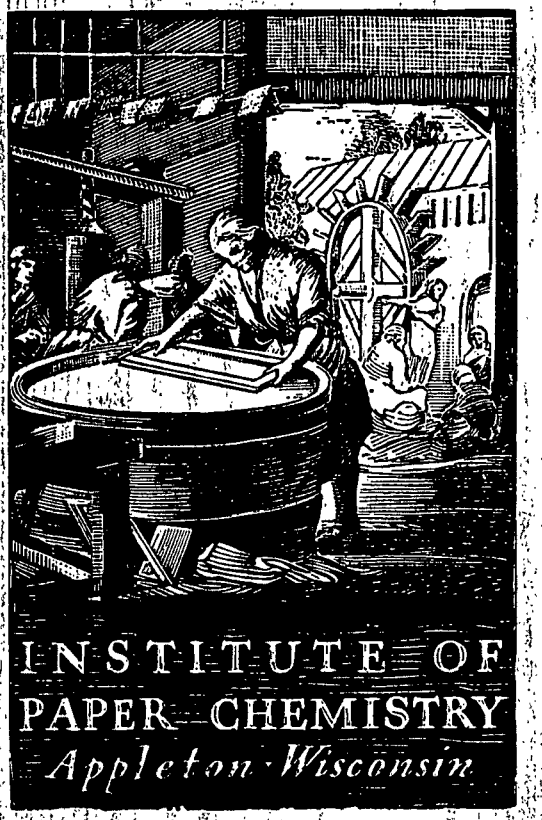

IMPROVED WEIGHT FACTORS FOR FIBER ANALYSIS

Project 3033

Report Three

A Progress Report

to

MEMBERS OF GROUP PROJECT 3033

July 24, 1973

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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MEMBERS OF GROUP PROJECT 3033

Crown Zellerbach Corporation

P. H. Glatfelter Company

Great Northern Paper Company

Hammermill Paper Company

Kimberly-Clark Corporation

The Mead Corporation

Scott Paper Company

St. Regis Paper Company

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

IMPROVED WEIGHT FACTORS FOR FIBER ANALYSIS

SUMMARY

Progress Report One included the results of weight factor determinations made on available pulp samples submitted by the participating companies of Project 3033. Progress Report Two was an extensive study of the weight factors of pulps prepared from (a) various species of southern yellow pine, and (b) hardwood species of red and white oak. The results of this investigation indicated that weight factor is strongly influenced by the degree of cooking, e.g., pulps prepared from juvenile and mature wood of loblolly and slash pine with screened yields of approximately 45% and a 40 Kappa number level were, on the average, 25% lower than pulps with screened yields of approximately 54% and a 115 Kappa number level.

No conclusions could be drawn from the data available in Progress Report Two as to the influence of site and geographic location on the weight factors of pulps prepared from species of southern yellow pine. The investigation did indicate that neither geographic origin or species had a significant effect on the weight factor values of pulp samples prepared from species of red and white oak.

Weight factors in this current study were determined on pulp samples prepared from hardwood species, other than oak, in which the cooperating companies of Project 3033 had expressed the most interest.

The present investigation confirmed that there is considerable variation in the weight factors of similarly prepared samples (i.e., same cook, yield, etc.) derived from different hardwood species. Pulps prepared from species of maple have a low coarseness and a weight factor of 0.32. Sweetgum, on the other hand, with a relatively high coarseness, had an average

weight factor of approximately 0.8, more than double the weight factor for maple. Pulps prepared from species of maple, hickory, and white ash had average weight factors <0.4. Populus sp. and species of white or red oak had average weight factor values >0.4 and <0.5. Pulps prepared from species of beech and white birch had average factors >0.5 and <0.6, while species of yellow poplar, black tupelo, and sweetgum had average weight factors >0.7 and <0.8.

The pulping of hardwoods has increased greatly in the past five years and the trend of increased use is expected to continue. Cooking of species mixtures and the need to identify the relative percentages of the various hardwood species in paper furnishes is expected to be an increasing problem. A set of relative factors based on "vessel counts" was developed as an aid for estimating the weighted percentages of various hardwood species contained in a pulp mixture. There is a considerable range in the average values of these vessel factors. Species of red oak have the highest factor of 6.0 while basswood has a relatively low vessel factor of 0.2. Pulps prepared from species of white oak have considerably lower vessel factor values than red oak pulps. All pulps prepared from diffuse porous wood species have lower factor values than pulps prepared from ring porous species, as would be expected.

Plans for the program during the next six months will include, primarily, the completion of weight factor determinations for all the remaining pulps prepared from high priority softwood species.

INTRODUCTION

The principal objectives of Project 3033 were to: (1) examine the weight factors of various pulps, particularly softwood and hardwood pulp samples prepared from different tree species of most interest to the participating companies of Project 3033; (2) examine the effect that geographic location, cook, yield, etc., may have on the weight factors of pulps prepared from the same wood species; (3) investigate weight factors for pulps prepared by the more recently developed pulping processes which may be of interest to cooperators of the project; (4) develop a set of relative factors for hardwood species based on vessel counts.

The weight factors of several authentic pulp samples submitted for investigation by the cooperators of the project were reported in Progress Report One. An extensive study was made and the results reported in Progress Report Two on the weight factors of different pulp samples prepared from various species of southern yellow pine and species of red and white oak.

The report that follows includes weight factor determinations made on high priority hardwood pulps prepared from species of sweetgum, tupelo gum, yellow poplar, white birch, American beech, Populus sp., maple, white ash, and hickory. Also developed and included in this report is a set of relative factors, based on "vessel counts" of pulp samples, for some of the more important hardwood species.

EXPERIMENTAL METHODS AND MATERIALS

METHODS

Standard Weight Factors

The methods employed in making the weight factor determinations were the same as outlined in the previous progress reports and were as follows.

A fifty-fifty mixture by weight of a standard pulp (i.e., cotton linters — J. H. Munktells Swedish Filtering Paper for Chromatography) with a known relative weight factor of 1.1 and the pulp under investigation are prepared by thoroughly mixing in a large Erlenmeyer flask. This fiber suspension is poured into six test tubes and each is diluted to the desired consistency (i.e., approximately 0.05%). Standard slides are prepared (a one-inch square field at each end of every slide) from each of the six pulp mixtures and the fibers mounted and differentially stained with Graff "C" stain (refer to TAPPI Standard T 401 m-60). The fibers are counted at a magnification of 100 diameters with the aid of a binocular microscope equipped with a mechanical stage and an eyepiece with a pointer. The fiber field is moved horizontally and all the fibers counted as they pass under the end of the pointer. The one square inch field is scanned five times on lines 4-mm. apart for a count which usually totals between 200-300 fibers. Both sides of the six slides are examined in this manner for each determination. Since the weight factor for the standard pulp is known, the relative weight factor for the pulp being examined is readily calculated.

SAMPLES

Weight factors of pulps, prepared from hardwood species of most interest to Project 3033 participating companies, were investigated during this particular

phase of the program. The pulps included samples submitted by: 1) various co-operators of the project and 2) laboratory pulps prepared under controlled conditions at The Institute of Paper Chemistry. A list of these pulps and all available pertinent information relating to them are presented in Tables I, II, and III.

TABLE I

PULPS SUBMITTED BY THE COOPERATING COMPANIES

Pulp No.	Cooperating Company	Wood Species	Origin	Cook	Total Yield, %	Screened Yield, %	Kappa No.
1	Great Northern	Beech	NE[a]	Na-bisulfite (No. 1108A)	46.47	44.62	14.9
2	Great Northern	Beech	NE[a]	Na-bisulfite (No. 1112B)	48.24	46.12	14.4
3	Scott	Beech	--	Unbl. kraft	--	--	--
4	Great Northern	Birch	NE[a]	Na-bisulfite (No. 1107B)	50.61	50.02	15.6
5	Scott	Birch	--	Unbl. kraft	--	--	--
6	Great Northern	Maple	NE[a]	Na-bisulfite (No. 1107A)	48.37	46.60	12.0
7	Hammermill	Maple	Penn.	C-E-H bleach soda	--	--	13.0
8	Hammermill	Maple	Wis.	Unbl. kraft	--	--	12.0
9	Great Northern	Populus sp.	NE[a]	Na-bisulfite (No. 1110A)	53.17	52.80	8.9
10	Scott	Populus sp.	--	Unbl. kraft	--	--	--
11	Riegel	Sweetgum, No. 1607	N.C.	Kraft (cook No. 308)	--	--	19.0
12	Riegel	Sweetgum, No. 901	La.	Kraft (cook No. 133)	--	--	15.0
13	Hammermill	Sweetgum	Ala.	C-E-D-E-D bl. kraft	--	--	14.0

[a]Samples believed to be from trees growing in Northeastern U.S.

TABLE II

KRAFT PULPS PREPARED FROM ACQUIRED WOOD SAMPLES AND PULPED AT THE INSTITUTE OF PAPER CHEMISTRY

Pulp No.	Wood Species	Origin	Tree Age, yr.	Height, ft.	D.B.H., in.	Total Yield, %	Kappa No.
1	White ash (3033-5)	N. Wis.	37	52	8.4	45.6	>9
2	Amer. beech (3033-26)	C. Wis.	37	45	6.5	49.2	14
3	White birch (3033-1)	N. Wis.	40	50	6.0	47.0	14
4	N. cottonwood (3033-25)	C. Wis.	12	40	6.5	52.4	13
5	S. cottonwood (3033-4)	Ala.	20	48	9.2	47.8	12
6	Hickory (3033-2)	C. Wis.	100	48	10.0	46.3	21
7	Red maple (3033-3)	N. Wis.	42	40	7.0	48.2	9
8	Soft maple (3033-7)	N. Wis.	42	50	7.0	52.0	20
9	Yellow-poplar (3033-23)	Va.	24	58.5	7.9	48.9	9
10	Yellow-poplar (3033-17)	Ala.	13	49	6.9	49.5	15
11	Sweetgum (3033-16)	Ala.	19	54	7.5	49.1	14
12	Sweetgum (3033-21)	Va.	32	59	7.4	47.7	14
13	Black tupelo (3033-22)	Va.	63	48.3	7.0	46.6	21
14	Black tupelo (3033-18)	Ala.	30	56	7.2	49.8	16
15	Aspen (3033-31)	Wis.	--	--	--	52.4	32
16	Aspen (3033-32)	Wis.	10	30	3.1	50.1	12

TABLE III

COOKING CONDITIONS

A. Great Northern Pulps

Time, hr.:min.	4:20
pH liquor	3.7
Top temperature, °C.	167
% SO_2, on wood	18
Liquor:wood ratio	4:1

B. Institute of Paper Chemistry Pulps

Digester charge, g.o.d.	50
Liquor-to-wood ratio	6:1
Active alkali as Na_2O, %	20
Sulfidity, %	25
Time to max. temp., min.	90
Time at max. temp., min.	75
Max. temp., °C.	175

DESCRIPTION OF WOOD SPECIES AND RESULTS OF WEIGHT FACTOR DETERMINATIONS

The wood of hardwood species is quite complex and the anatomical characteristics may vary significantly between species. A brief description of the gross and minute features (1,2) of some of the wood species included in this current study were given in Progress Report One and, for convenience, are included in the following section with the descriptions of other wood species investigated. Photomicrographs (SEM[1]) of transverse wood surface areas at magnifications of 50 and 200 diameters and also a photomicrograph of the pulp furnish have been included for each species. The results of weight factor determinations made on the various pulp samples are recorded after the description of each species.

AMERICAN BEECH (*Fagus grandifolia* Ehrh.)

General Description and Minute Anatomy

American beech is a diffuse porous wood containing small pores, indistinct without a hand lens, usually crowded and largest in the earlywood, decreasing in number and size through the central portion of the growth ring, and very small in the latewood. The wood is heavy (sp.gr. approximately 0.56 green, 0.67 ovendry). The rays are of two types, broad (oak type) and narrow. The broad rays are 12-25 plus seriate and one to several millimeters in height along the grain. The narrow rays are numerous, 1-5 seriate and up to 500 plus micrometers in height. The volume occupied by the rays is 20.4%. The parenchyma is abundant, metatracheal, and metatracheal-diffuse. There are between 50-200 vessels per square millimeter, the largest 60 to 90 μm. in diameter and

[1]SEM — Scanning electron microscope.

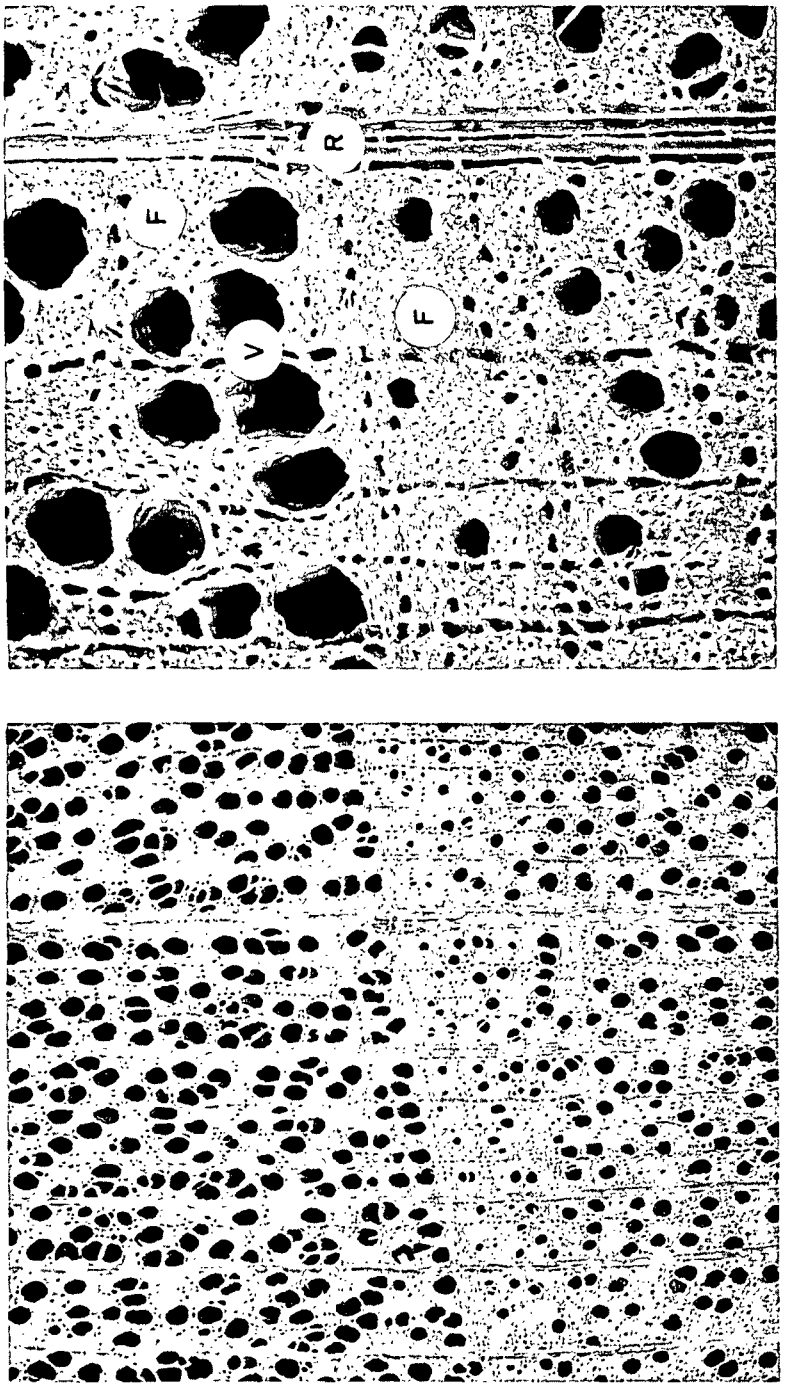
approximately 0.6 mm. in length. Tyloses are present in the heartwood. The fibers are thick walled, 16-22 μm. in diameter and 1.3 mm. (range 0.6 to 1.9 mm.) in length.

Photomicrographs (SEM) of transverse surface areas prepared from wood samples of American beech are illustrated in Fig. 1 and 2. A photomicrograph of the furnish of a pulp sample prepared from American beech is illustrated in Fig. 3.

Weight Factor Determination

The results of weight factor determinations made on pulp samples prepared from American beech are shown in Table IV.

The beech pulps represent two types of pulping processes (Na-bisulfite and kraft) and the trees are from two geographic origins (Lake States and Northeast). The pulp yields and Kappa numbers of the pulps were similar (unknown for the Scott Paper Company sample). There appears to be no major difference in the weight factors obtained and there is no evidence that the pulping procedure or geographic origin had any influence on the weight factors obtained. The recommended weight factor for beech pulps cooked to yields of 45 to 50% and/or a Kappa number of 14 to 15 is 0.52.



Figures 1 and 2. American Beech (Fagus grandifolia Ehrh.) Photomicrographs (SEM) of Transverse Surface of American Beech. Vessels (V), Fibers (F), Ray (R). 50-200 Vessels per sq.mm. Magnification — 50 and 200 Diameters

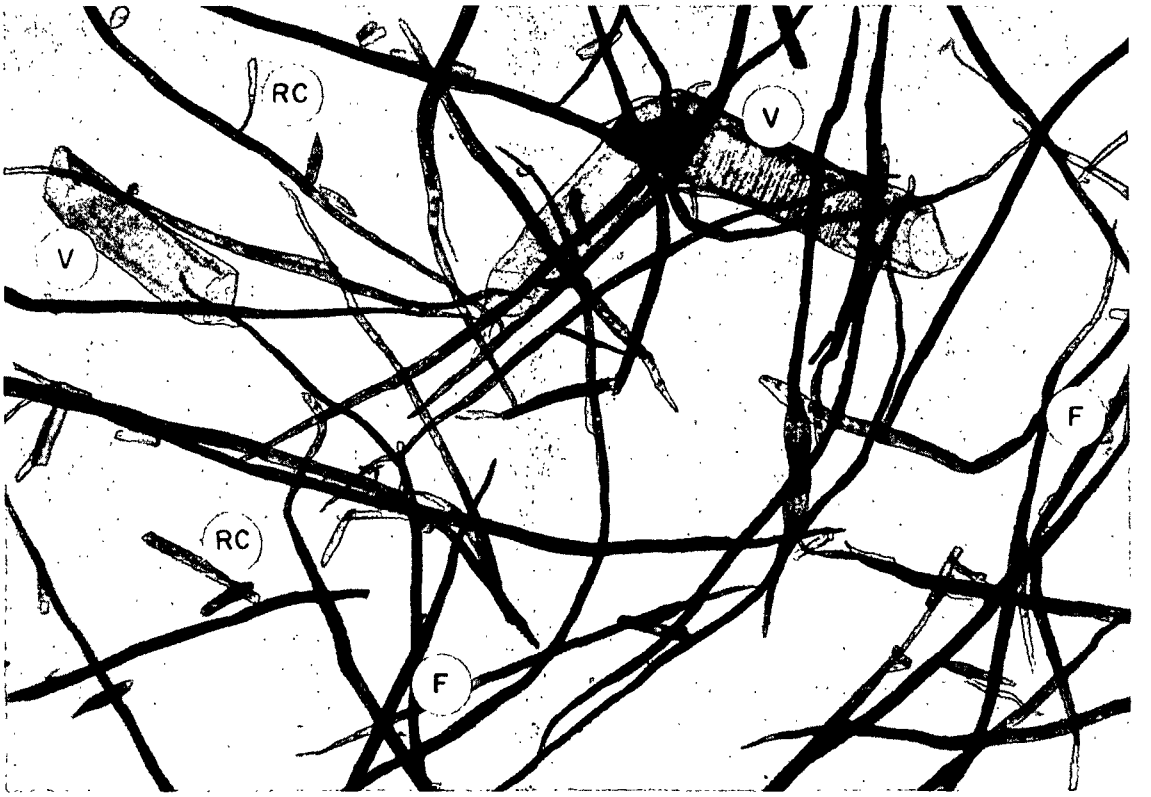


Figure 3. Pulp Sample of Beech Unbleached Kraft (Submitted by Scott Paper Co.) Vessel Elements (V), Fibers (F), Ray Cells (RC). Magnification — 90 Diameters. Average Weight Factor of Beech Chemical Pulps — 0.52

TABLE IV

WEIGHT FACTOR DETERMINATIONS ON AMERICAN BEECH PULP SAMPLES

Pulp Samples	Weight Factor Determination — Analyst A	Analyst B	Av.
1. Beech unbleached Na-bisulfite (No. 1108A) — Great Northern Paper Co.	0.52	0.52	0.52
2. Beech unbleached Na-bisulfite (No. 1112B) — Great Northern Paper Co.	0.52	0.49	0.50
3. Beech unbleached kraft — Scott Paper Co.	0.49	0.50	0.50
4. Beech unbleached kraft — IPC No. 3033-26	0.53	0.55	0.54

WHITE ASH (Fraxinus americana L.)

General Description and Minute Anatomy

The wood of white ash is heavy (sp.gr. 0.50-0.56 green, 0.58-0.64 oven-dry). It is typically ring porous, containing large earlywood pores distinctly visible to the naked eye, forming a band 2-4 pores in width. The latewood pores are small, barely visible to the naked eye, solitary and in multiples of 2-3. The rays are indistinct or are barely visible to the naked eye, unstoried, 1-3 seriate and homogeneous. The volume occupied by the rays is 12%. Parenchyma are visible with a hand lens in the latewood, forming a narrow sheath about the pores and frequently uniting them laterally toward the outer margin of the ring. There are 6-15 vessels per square millimeter. The largest earlywood vessels are 150-260 μm. in diameter and approximately 0.29 mm. in length. Vasicentric tracheids are present and confined to the immediate vicinity of the earlywood vessels. The fibers are thin to medium thick walled, 12-22 μm. in diameter and 1.3 mm. in length. The volume occupied by the fibers is approximately 70%.

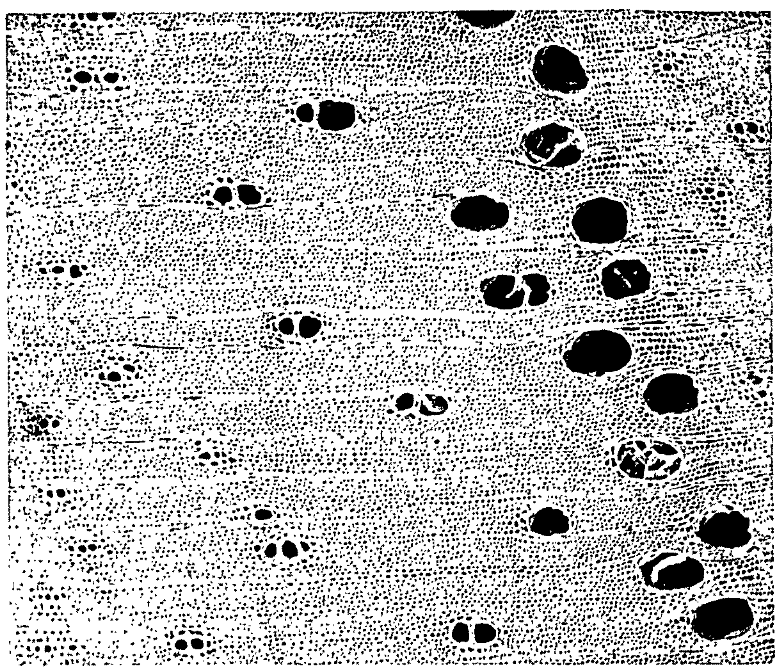
Photomicrographs (SEM) of transverse surface areas of white ash are illustrated in Fig. 4 and 5.

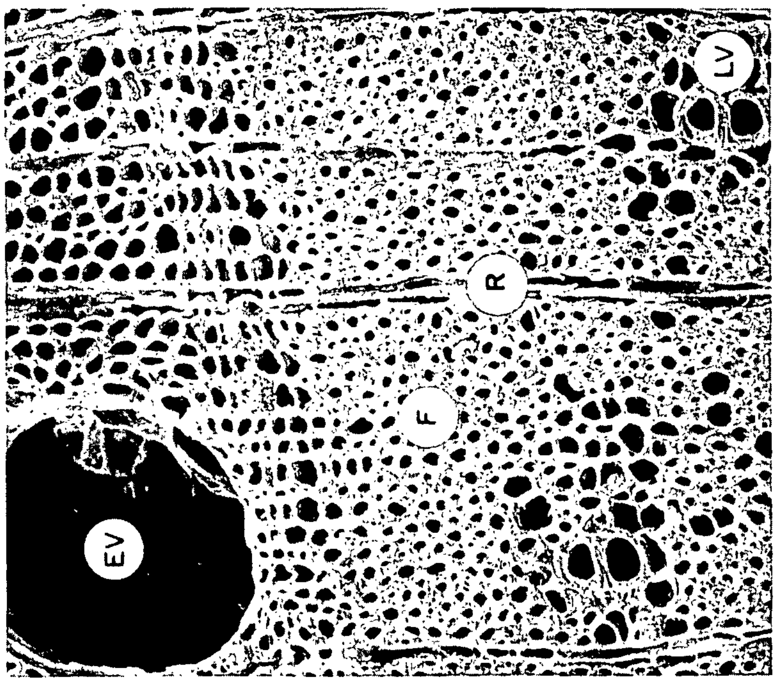
Weight Factor Determination

The results of a weight factor determination made on a pulp sample of white ash are shown in Table V.

The results suggest that chemical pulps prepared from species of white ash are quite fine and are similar to that of shagbark hickory.

A photomicrograph of the pulp furnish is illustrated in Fig. 6.





Figures 4 and 5. White Ash (<u>Fraxinus Americana</u> L.) Photomicrographs (SEM) of Transverse Surface of <u>White Ash</u>. <u>Earlywood</u> Vessels (EV), Latewood Vessels (LV), Fibers (F), Ray (R). 6-15 Vessel Elements per sq.mm. Magnification — 50 and 200 Diameters

TABLE V

WEIGHT FACTOR DETERMINATION ON A WHITE ASH PULP SAMPLE

Pulp Sample	Weight Factor Determination — Analyst A	Analyst B	Av.
White ash unbleached kraft — IPC Sample 3033-5	0.39	0.38	0.38

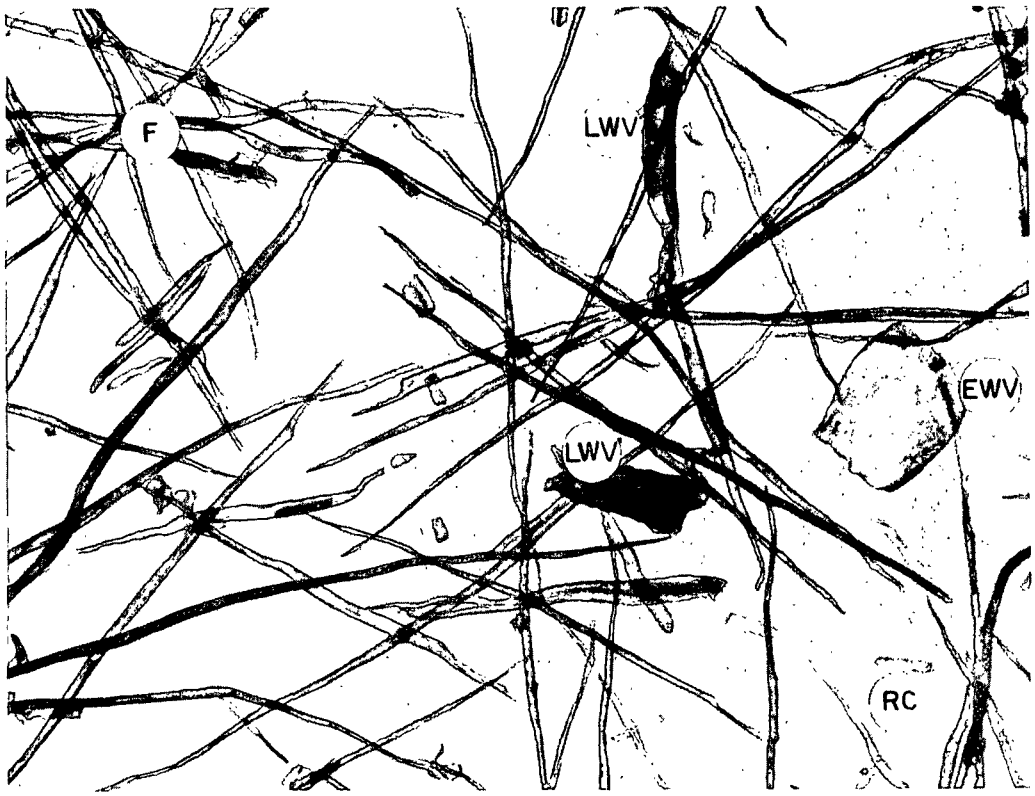


Figure 6. Pulp Sample of White Ash Unbleached Kraft (IPC 3033-5). Earlywood Vessel Element (EWV), Latewood Vessel Element (LWV), Fibers (F), Ray Cells (RC). Magnification — 90 Diameters. Weight Factor — 0.38

SOFT MAPLE (Red Maple, Acer rubrum L.)

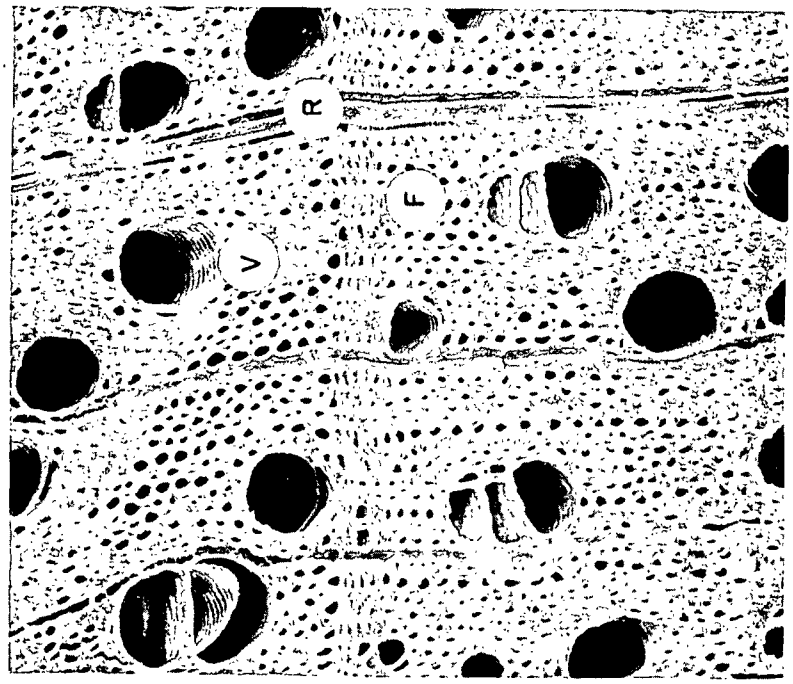
General Description and Minute Anatomy

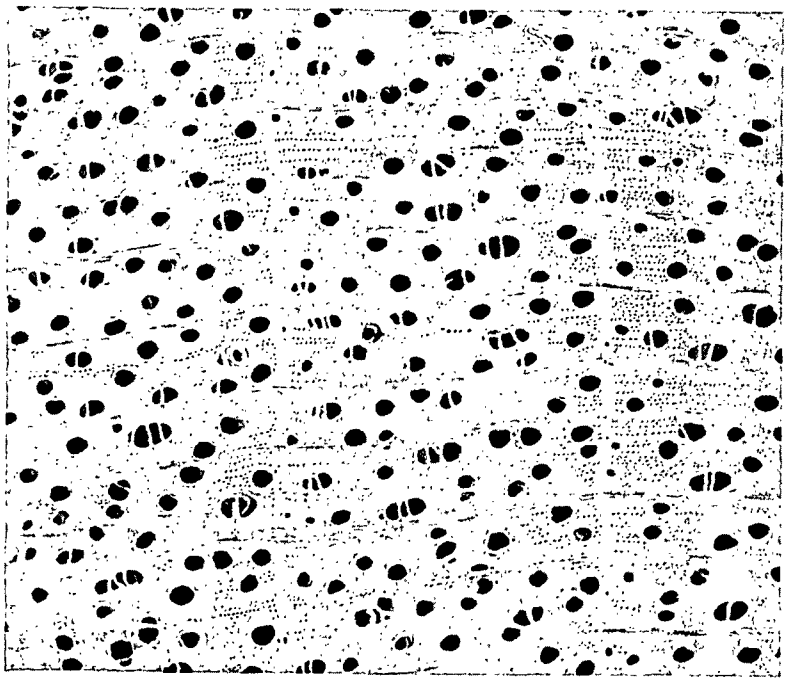
Red maple, along with silver maple (Acer saccharinum), is classified as a soft maple. Red maple is a diffuse-porous wood containing small pores, indistinct without a hand lens, evenly distributed throughout the growth ring. The wood is moderately heavy (sp.gr. 0.44-0.49 green, 0.51-0.55 ovendry). The rays are visible to the naked eye, intergrading in width, the broadest about as wide as the largest pores, forming a pronounced close ray fleck on the radial or quarter surface. Parenchyma cells are not visible. There are between 30-80 vessels per square millimeter, the largest 60-80 µm. in diameter and averaging 0.42 mm. in length. The fibers are thin to moderately thick-walled, 16 to 30 µm. in diameter and 0.7 mm. (0.3 to 1.1 mm.) long. The volume occupied by the vessels and fibers is 18.0 and 68.7%, respectively. The rays are unstoried, 1-5 seriate and essentially homogeneous. The volume occupied by the rays is 13.3%.

Photomicrographs (SEM) of transverse surface areas of red maple are illustrated in Fig. 7 and 8 and a photomicrograph of the pulp furnish is illustrated in Fig. 9.

Weight Factor Determination

The results of weight factor determinations which have been made on pulp samples prepared from species of maple are shown in Table VI.





Figures 7 and 8. Red Maple (Acer rubrum L.) Photomicrographs (SEM) of the Transverse Surface of Red Maple. Vessel (V), Fibers (F), Ray (R). 30-80 Vessels per sq.mm. Magnification — 50 and 200 Diameters

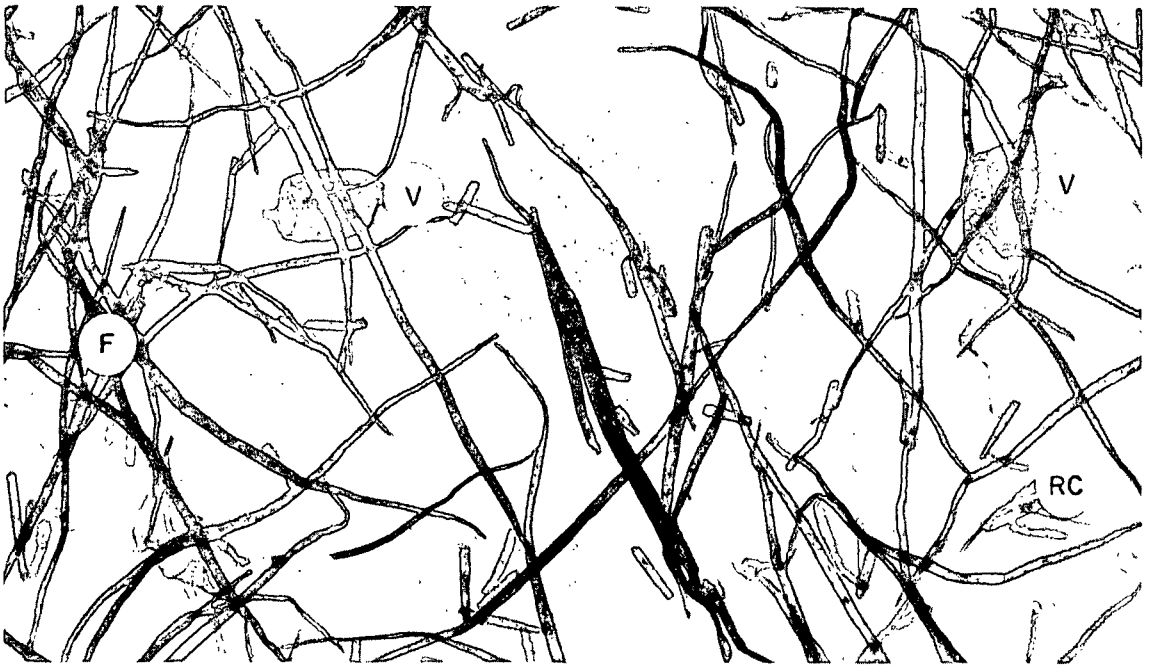


Figure 9. Pulp Sample of Soft Maple Unbleached Kraft (IPC 3033-7). Vessel (V), Fibers (F), Ray Cells (RC). Magnification — 90 Diameters. Average Weight Factor of Maple Chemical Pulps — 0.33

TABLE VI

WEIGHT FACTOR DETERMINATIONS ON MAPLE PULP SAMPLES

Pulp Samples	Weight Factor Determination — Analyst A	Analyst B	Av.
1. Maple[a] unbleached Na-bisulfite (No. 1107A) — Great Northern Paper Co.	0.33	0.32	0.32
2. Soft maple unbleached kraft — IPC No. 3033-7	0.31	0.30	0.30
3. Maple[a] C-E-H bleached soda — Hammermill Paper Co.	0.34	0.32	0.33
4. Maple[a] unbleached kraft — Hammermill Paper Co.	0.38	0.36	0.37
5. Red maple unbleached kraft — IPC No. 3033-3	0.28	0.31	0.30

[a]Species of maple unknown, believed very likely to be sugar maple (Acer saccharum Marsh.).

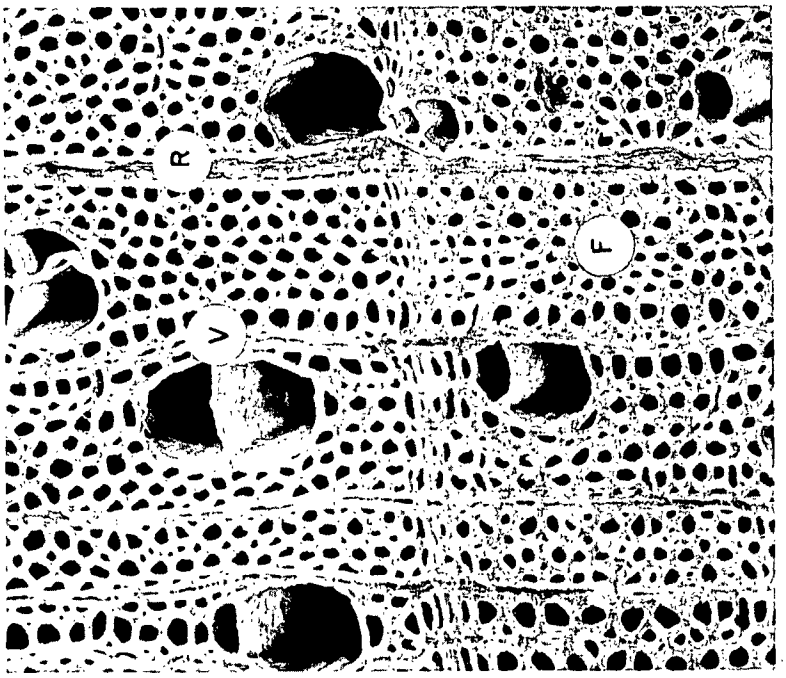
BIRCH [White or Paper Birch (Betula papyrifera Marsh.);
Yellow Birch (Betula alleghanienis Britton);
Sweet, Black, or Cherry Birch (Betula lenta L.);
River or Red Birch (Betula nigra L.);
Gray Birch (Betula populifolia (Marsh.)]

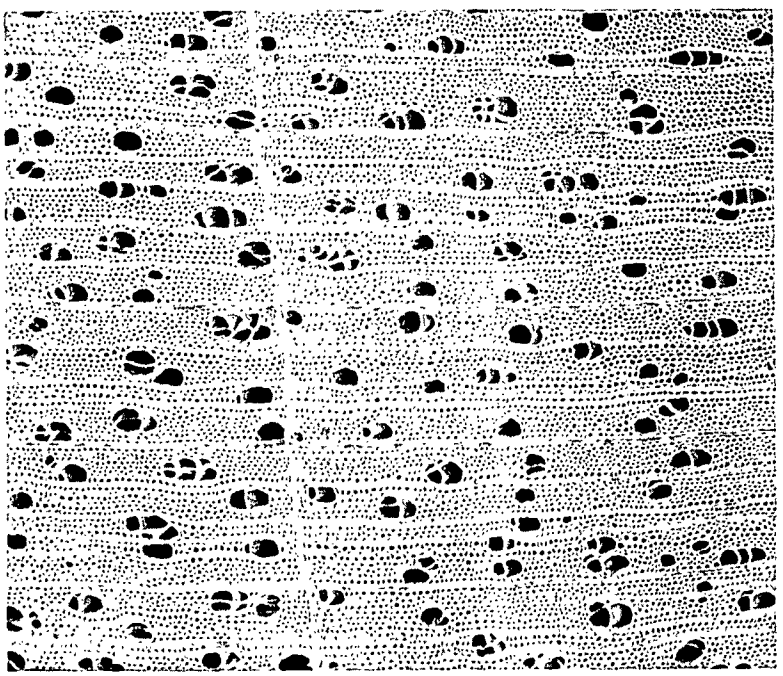
General Description and Minute Anatomy

The woods of the different species of Betula cannot be separated on the basis of either gross structure or minute anatomy. Sweet birch and yellow birch are harder, heavier, and stronger than the other native species.

The wood of the species is heavy to very heavy (sp.gr. 0.45-0.60 green, 0.55-0.71 ovendry). The growth rings are not distinct without a hand lens. The wood is diffuse porous, the pores appearing as whitish dots to the naked eye, nearly uniform in size and evenly distributed throughout the growth ring. Parenchyma cells are not visible. The rays are fine, narrower than the largest pores and generally not distinct to the naked eye. There are 50-100 vessels per sq.mm. and the largest are 60-160 µm. in diameter and approximately 1.0 mm. in length. The fibers are thin to moderately thick walled, 20-36 µm. in diameter and average approximately 1.4 mm. in length. The rays are unstoried, 1-5 seriate and homogeneous. The volume occupied by the vessels, fibers and rays is 21.4, 65.8, and 10.8%, respectively. The longitudinal parenchyma are apotracheal-diffuse, and in aggregates, paratracheal and marginal. The volume occupied by parenchyma cells is 2.0%.

Photomicrographs (SEM) of transverse surface areas of a sample of white birch are illustrated in Fig. 10 and 11. A photomicrograph of a pulp furnish is shown in Fig. 12. The recommended weight factor for birch species is 0.56 and, as such, has the highest weight factor of any Northeast or Lake States species of hardwood investigated.





Figures 10 and 11. White Birch (Betula papyrifera Marsh.) Photomicrographs (SEM) of Transverse Surface of White Birch. Vessel (V), Fibers (F), Ray (R). 50-100 Vessels per sq.mm. Magnification — 50 and 200 Diameters

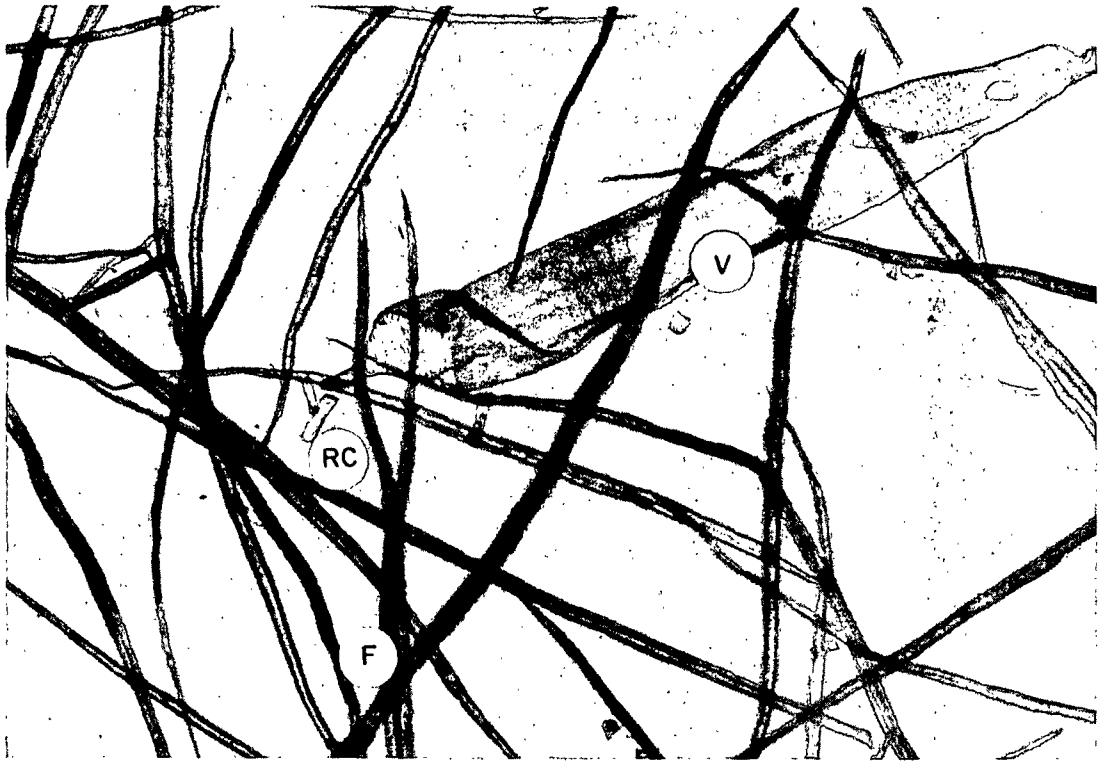


Figure 12. Pulp Sample of Birch Unbleached Kraft (Submitted by Scott Paper Co.). Vessel Elements (V), Fibers (F), Ray Cells (RC). Magnification — 90 Diameters. Average Weight Factor of Birch Chemical Pulps — 0.56

Weight Factor Determination

The results of weight factor determinations made on two pulp samples prepared from species of birch are shown in Table VII.

TABLE VII

WEIGHT FACTOR DETERMINATIONS ON TWO BIRCH PULP SAMPLES

Pulp Samples	Weight Factor Determination		
	Analyst A	Analyst B	Av.
1. White birch unbleached kraft — IPC No. 3033-1	0.54	0.51	0.52
2. Birch[a] unbleached kraft — Scott Paper Co.	0.60	0.59	0.60

[a]Exact species of birch involved is unknown.

POPULUS SP. [Quaking Aspen, Trembling Aspen (Populus tremuloides Michx.);
Bigtooth Aspen (Populus grandidentata Michx.);
Eastern Cottonwood, Eastern Poplar (Populus deltoides (Bartr);
Balsam Poplar, Tacamahaca Poplar (Populus balsamifera L.);
Swamp Cottonwood, Swamp Poplar (Populus heterophylla L.);
Black Cottonwood (Populus trichocarpa Torr. & Gray), etc.]

General Description and Minute Anatomy

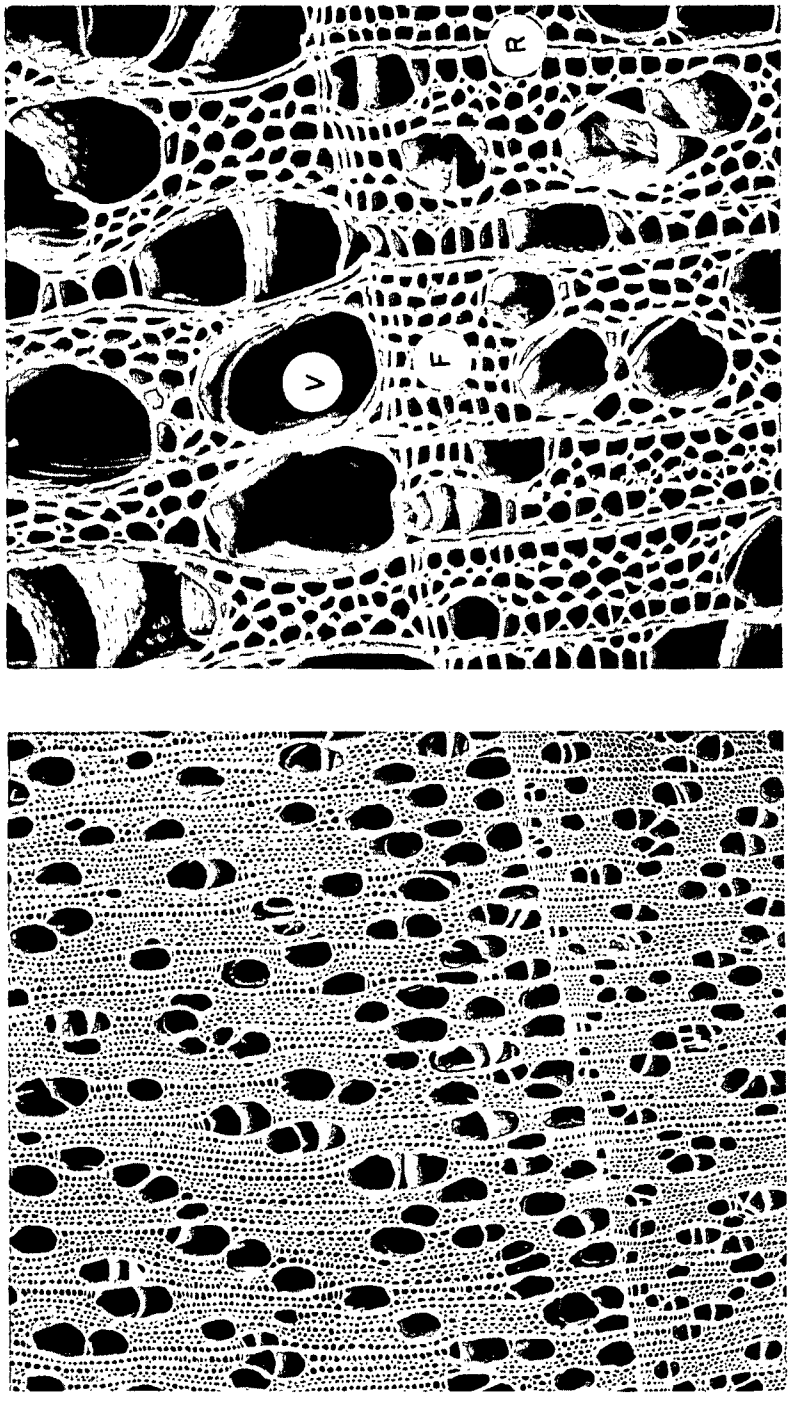
The woods of quaking and bigtooth aspen are quite similar and cannot be separated from each other with certainty. The woods of the cottonwoods are quite similar to aspen but coarser in texture. The following description is for species of aspen.

The woods of quaking and bigtooth aspen are moderately light to light (sp.gr. approximately 0.37 green, 0.44 ovendry). The growth rings are inconspicuous and narrow to wide. The pores are numerous, small, the largest barely visible to the naked eye in the earlywood, decreasing gradually in size through the latewood. The wood is semiring to diffuse porous. The parenchyma are terminal and generally not visible to the naked eye. The rays are fine, scarcely visible with a hand lens. The vessels number 30-120 per sq.mm., the largest 90-160 µm. in diameter and 0.65 mm. in length. The fibers are thin to moderately thick walled, occasionally gelatinous, 15 to 30 µm. in diameter and 1.04 mm. (0.4 to 1.9 mm.) in length. The volume occupied by the vessels is 33.8% while that for the fibers is 55.1%. The rays are unstoried, uniseriate, up to 25 cells in height and homogeneous. The volume occupied by the rays is 11.1%.

Photomicrographs (SEM) of transverse surface areas of a sample of Populus sp. are illustrated in Fig. 13 and 14.

Weight Factor Determination

The results of weight factor determinations made on Populus sp. pulp samples are shown in Table VIII.



Figures 13 and 14. Eastern Cottonwood (Populus deltoides Bartr.) Photomicrographs (SEM) of Transverse Surface of Cottonwood. Vessel (V), Fibers (F), Ray (R). 30-120 Vessels per sq.mm. Magnification — 50 and 200 Diameters

TABLE VIII

WEIGHT FACTOR DETERMINATIONS ON POPULUS PULP SAMPLES

Pulp Sample	Weight Factor Determination		
	Analyst A	Analyst B	Av.
1. Populus sp.[a] unbleached Na-bisulfite (No. 1110A) — Great Northern Paper Co.	0.51	0.49	0.50
2. Populus sp.[a] unbleached kraft — Scott Paper Co.	0.41	0.42	0.42
3. Cottonwood (Ala.) unbleached kraft — IPC No. 3033-4	0.47	0.48	0.48
4. Cottonwood (Wis.) unbleached kraft — IPC No. 3033-25	0.38	0.39	0.38
5. Aspen (Wis.) unbleached kraft — IPC cook No. 1	0.47	0.48	0.48
6. Aspen (Wis.) unbleached kraft — XT-12-58	0.51	0.49	0.50

[a]Species of Populus unknown, believed to be aspen from the Northeast.

A photomicrograph of a pulp furnish prepared from cottonwood is illustrated in Fig. 15.

The weight factors for aspen and cottonwood were somewhat more variable than the other species considered. The lowest weight factor for Populus sp. was obtained from a 12-year-old rapidly growing sample of northern cottonwood. The variation is not great enough to warrant the use of more than one weight factor and 0.48 is recommended for use for all species of Populus.

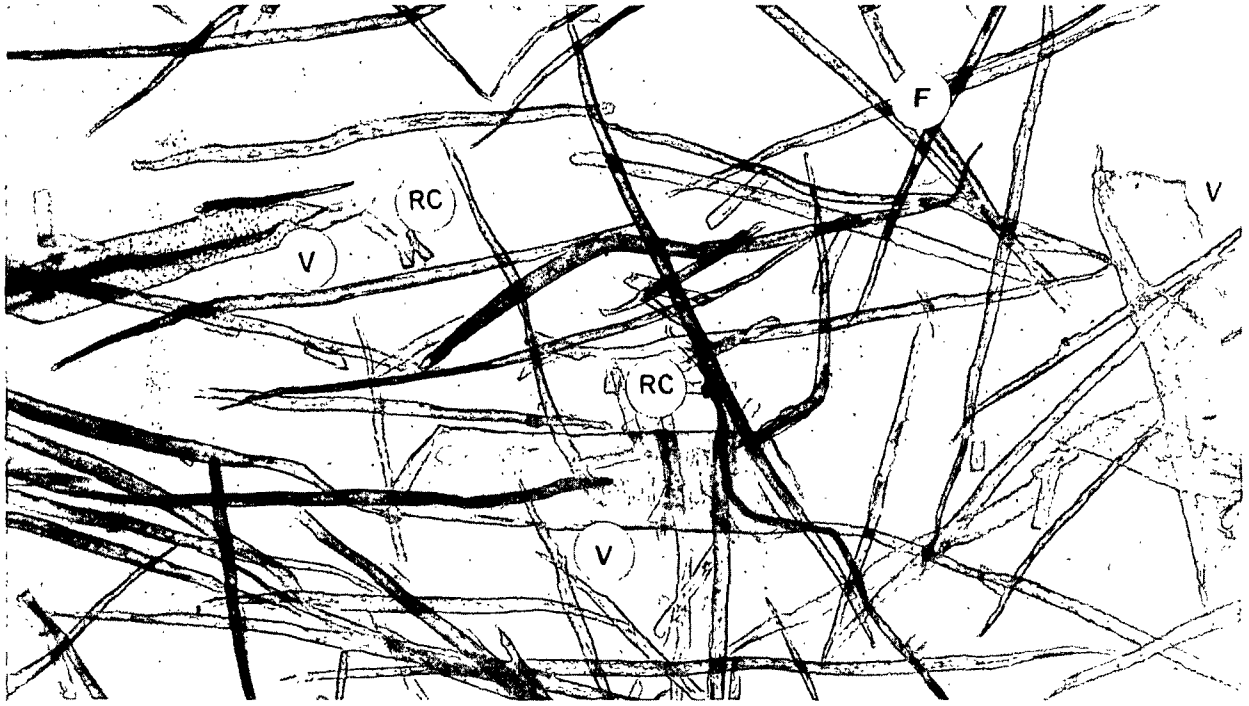


Figure 15. Pulp Sample of Cottonwood (Ala.), Unbleached Kraft, IPC No. 3033-4. Vessel (V), Fibers (F), Ray Cells (RC). Magnification — 90 Diameters. Average Weight Factor of Populus sp. Chemical Pulps — 0.44

SWEETGUM OR RED-GUM (Liquidambar styraciflua L.)

General Description and Minute Anatomy

Sweetgum is a diffuse-porous wood containing numerous, small, uniform pores invisible to the naked eye, evenly distributed throughout the growth ring. The wood is moderately heavy (sp.gr. 0.44 green, 0.53 ovendry). Parenchyma are not visible. The rays are not distinct to the naked eye, are very close, and seemingly occupy half of the area on the transverse surface. Longitudinal wound (traumatic) gum canals are sometimes present in tangential rows, and usually appear at wide intervals. The vessels average 120-180 per sq.mm. The largest vessels are between 60-95 µm. in diameter and average approximately 1.32 mm. in length. The fiber tracheids are moderately thick-walled, 20-40 µm.

in diameter, and have an average length of 1.8 mm. (1.0-2.5 mm.). The volume occupied by the vessels and fibers is 54.9 and 26.8%, respectively. The rays are unstoried, 1-3 (mostly 2), seriate and mostly heterogeneous. The volume occupied is 18.3%.

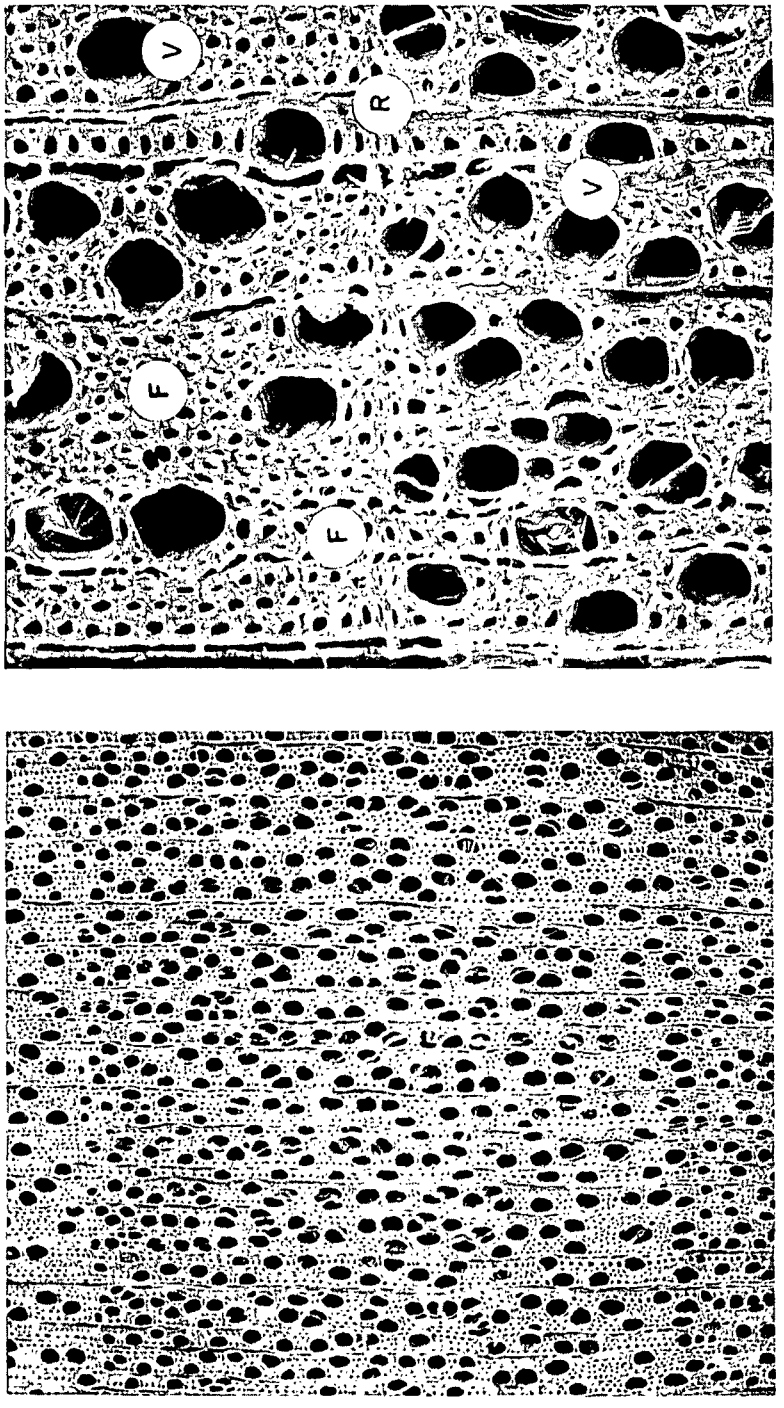
Photomicrographs (SEM) of the transverse surface area of sweetgum are illustrated in Fig. 16 and 17.

Weight Factor Determination

Weight factor determinations made on pulps prepared from species of sweetgum are shown in Table IX.

A photomicrograph of a pulp furnish prepared from sweetgum is illustrated in Fig. 18.

The five samples of sweetgum offer an opportunity to examine the influence of geographic origin on weight factor. The pulps are all kraft pulps and range in Kappa number from 14 to 19. The geographic origins include Virginia, North Carolina, Alabama, and Louisiana. There appears to be no significant difference in weight factor due to origin and the use of a weight factor of 0.80 is suggested for sweetgum.



Figures 16 and 17. Sweetgum (Liquidambar styraciflua L.) Photomicrographs (SEM) of Transverse Surface of Sweetgum. Vessel (V), Fibers (F), Ray (R). 120-180 Vessels per sq.mm. Magnification — 50 and 200 Diameters

TABLE IX

WEIGHT FACTOR DETERMINATIONS ON SWEETGUM PULP SAMPLES

Pulp Samples	Weight Factor Determination		
	Analyst A	Analyst B	Av.
1. Sweetgum (Va.) unbleached kraft — IPC No. 3033-21	0.75	0.75	0.75
2. Sweetgum (Ala.) unbleached kraft — IPC No. 3033-16	0.77	0.69	0.73
3. Sweetgum (Ala.) bleached kraft — Hammermill Paper Co.	0.81	0.86	0.84
4. Sweetgum (La.) unbleached kraft (Sample No. 901) — Riegel Paper Corp.	0.74	0.72	0.73
5. Sweetgum (N.C.) unbleached kraft (Sample No. 1607) — Riegel Paper Corp.	0.88	0.91	0.90

Figure 18. Pulp Sample of Sweetgum Bleached Kraft (Submitted by Hammermill Paper Co.). Fiber Tracheids (FT), Vessel Elements (V), Ray Cells (RC). Magnification — 90 Diameters. Average Weight Factor of Sweetgum Chemical Pulps — 0.79

BLACK TUPELO OR BLACKGUM [Black Tupelo, Blackgum, Pepperidge (Nyssa sylvatica Marsh.)]

General Description and Minute Anatomy

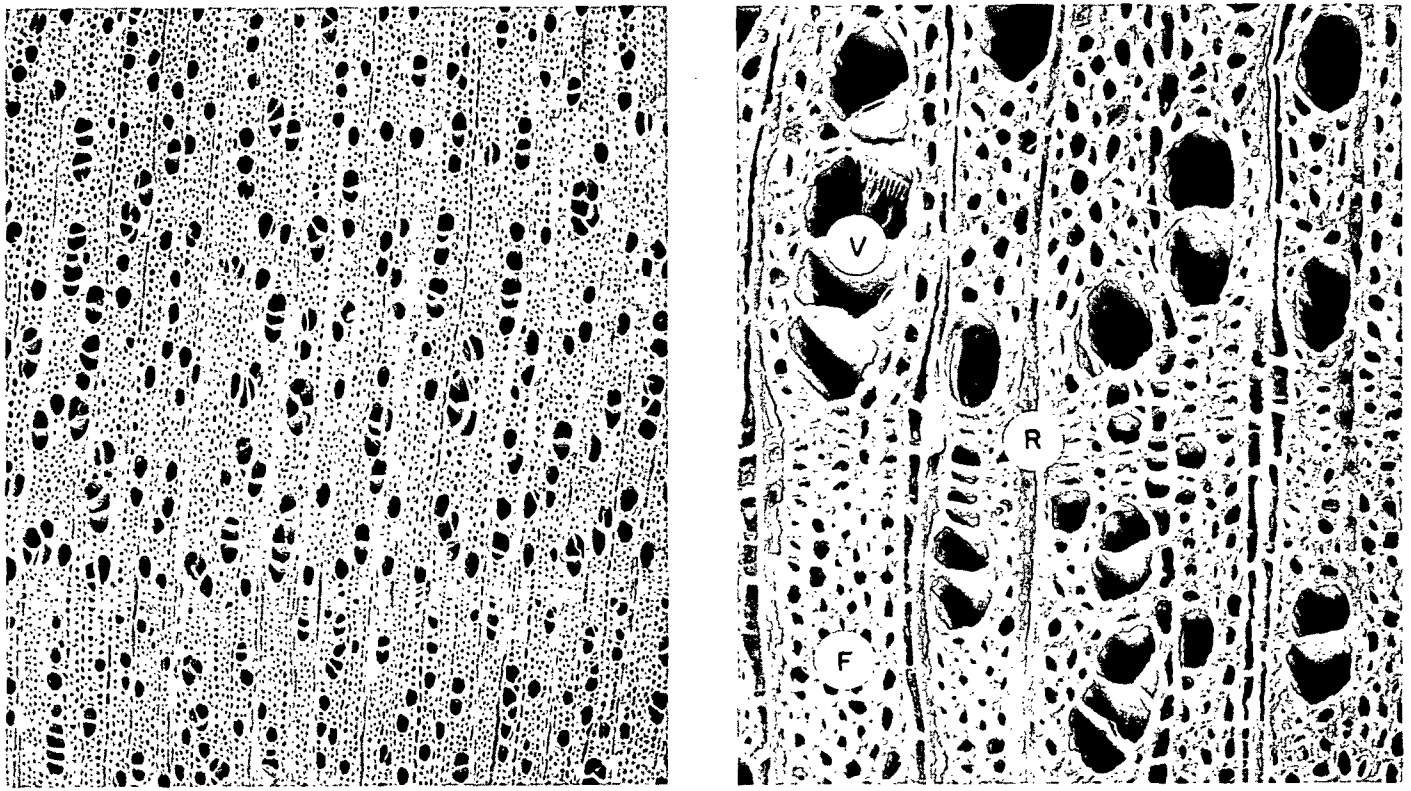
The wood of black tupelo is moderately heavy (sp.gr. approximately 0.46 green, 0.54 ovendry). The growth rings are generally indistinct even under a hand lens. The wood is diffuse porous, the pores small, not visible to the naked eye, nearly uniform in size, numerous and fairly evenly distributed, solitary or occasionally in short radial groups and in multiples. Parenchyma are not visible. Rays are fine, not distinct on the transverse surface without a hand lens. There are 90 to 180 vessels per square millimeter, the largest 60-90 μm. in diameter and approximately 1.33 mm. in length. The volume occupied is approximately 3.8%. The parenchyma are paratracheal and metatracheal-diffuse, the cells scattered. The fiber tracheids are moderately thick to thick-walled, 20-32 μm. in diameter and average approximately 1.8 mm. in length. The volume occupied by the fibers is approximately 45%. There are 8-13 rays per millimeter (cross section), unstoried, 1-4 seriate, heterogeneous and less than 60 μm. in height along the grain. The volume occupied by the rays is approximately 17%.

Black tupelo, swamp tupelo, and water tupelo are difficult to separate with certainty, even at high magnifications, but the last two woods are usually somewhat softer, lighter, and more porous with more crowded, slightly larger vessels.

Photomicrographs (SEM) of transverse surface areas of black tupelo are illustrated in Fig. 19 and 20.

Weight Factor Determinations

The results of weight factor determinations made on pulps prepared from species of black tupelo are shown in Table X.



Figures 19 and 20. Black Tupelo (Nyssa sylvatica Marsh.) Photomicrographs (SEM) of the Transverse Surface of Black Tupelo. Vessel (V), Fibers (F), Ray (R). 90-180 Vessels per sq.mm. Magnification — 50 and 200 Diameters

TABLE X

WEIGHT FACTOR DETERMINATIONS ON BLACK TUPELO PULPS

Pulp Sample	Weight Factor Determination — Analyst A	Analyst B	Av.
1. Black tupelo (Ala.) unbleached kraft — IPC Sample 3033-18	0.76	0.70	0.73
2. Black tupelo (Va.) unbleached kraft — IPC Sample 3033-22	0.73	0.69	0.71

Black tupelo has wood properties similar to those of sweetgum and, based upon pulp samples from trees growing in Virginia and Alabama, has a similar but slightly lower weight factor. Use of 0.72 is recommended when black tupelo is known to be part of the furnish.

A photomicrograph of a pulp furnish prepared from black tupelo is illustrated in Fig. 21.

Figure 21. Pulp Sample of Black Tupelo Unbleached Kraft (IPC 3033-22). Vessel (V), Fiber Tracheid (FT), Ray Cells (RC). Magnification — 90 Diameters. Average Weight Factor of Black Tupelo Chemical Pulps — 0.72

YELLOW-POPLAR OR TULIP POPLAR (Liriodendron tulipifera L.)

General Description and Minute Anatomy

The wood of yellow-poplar is diffuse porous, containing small pores, not visible without a lens, fairly uniformly distributed throughout the ring, solitary and in multiples of 2 to several. The wood is moderately light (sp.gr. approximately 0.38 green, 0.43 ovendry). Parenchyma are terminal, the line plainly visible to the naked eye. Rays are distinct to the naked eye (cross section), nearly uniform in width. There are 60-180 vessels per square millimeter, the largest 80-130 μm. in diameter and averaging 0.89 mm. in length. The fibers are thin to moderately thick-walled, 24-40 μm. in diameter and 1.9 mm. (0.8 to 2.7 mm.) in length. The volume occupied by the vessels and fibers is 37 and 49%, respectively. The rays are unstoried, 1 to 5 seriate and homogeneous to heterogeneous. The volume occupied by the rays is approximately 14%.

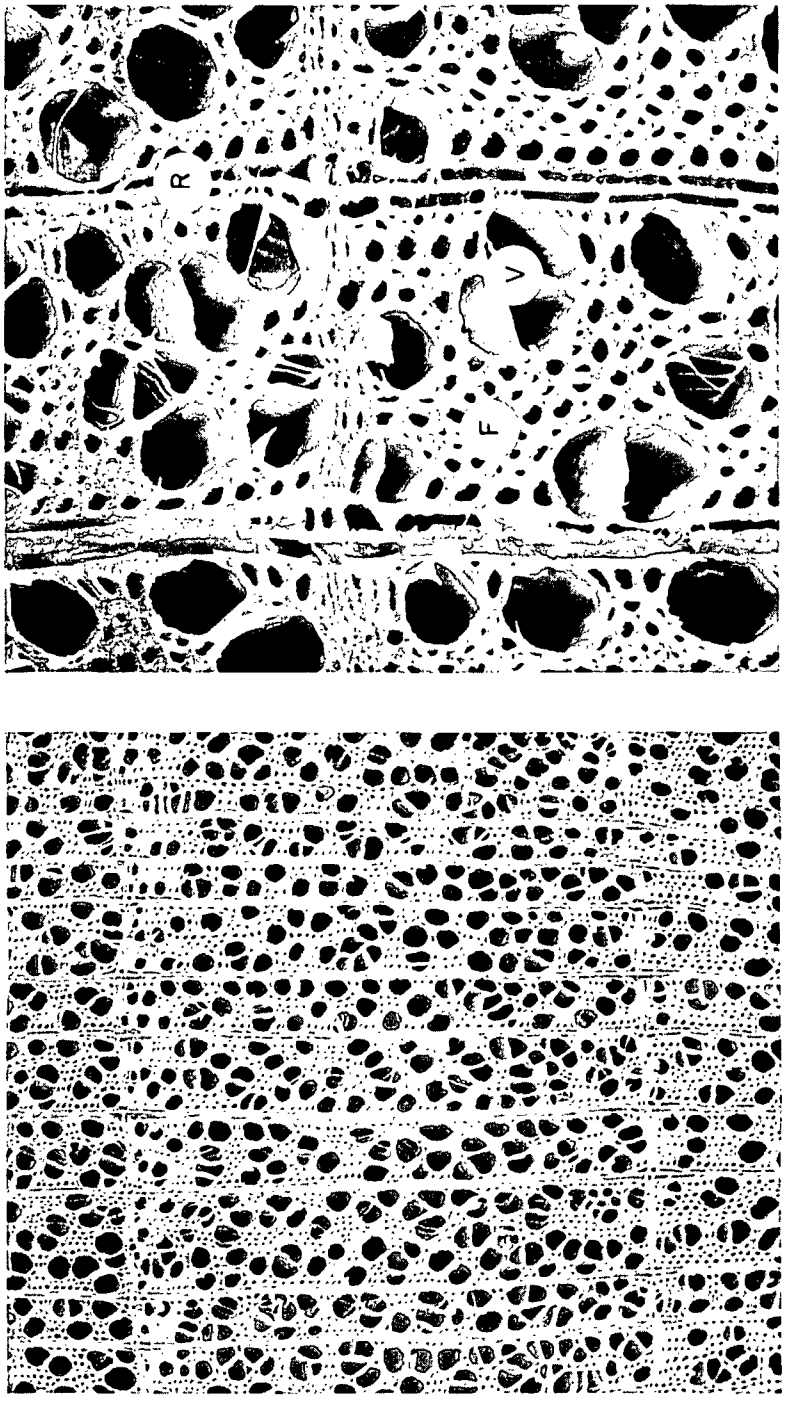
Photomicrographs (SEM) of transverse surface areas of yellow-poplar are illustrated in Fig. 22 and 23.

Weight Factor Determination

The results of weight factor determinations made on pulp samples prepared from species of yellow-poplar are shown in Table XI.

The two yellow-poplar samples came from the same geographic locations (Alabama and Virginia) as the two black tupelo samples. The weight factors for the two species are almost identical and neither species demonstrated any difference due to geographic origin.

A photomicrograph of a pulp furnish of yellow-poplar is illustrated in Fig. 24.



Figures 22 and 23. Yellow-Poplar (Liriodendron tulipifera L.) Photomicrographs (SEM) of Transverse Surface of Yellow-Poplar. Vessel (V), Fibers (F), Ray (R). 60-180 Vessels per sq.mm. Magnification — 50 and 200 Diameters

TABLE XI

WEIGHT FACTOR DETERMINATIONS OF YELLOW-POPLAR PULPS

Pulp Sample	Weight Factor Determination — Analyst A	Analyst B	Av.
1. Yellow-poplar (Ala.) unbleached kraft — IPC No. 3033-17	0.72	0.69	0.70
2. Yellow-poplar (Va.) unbleached kraft — IPC No. 3033-23	0.78	0.70	0.74

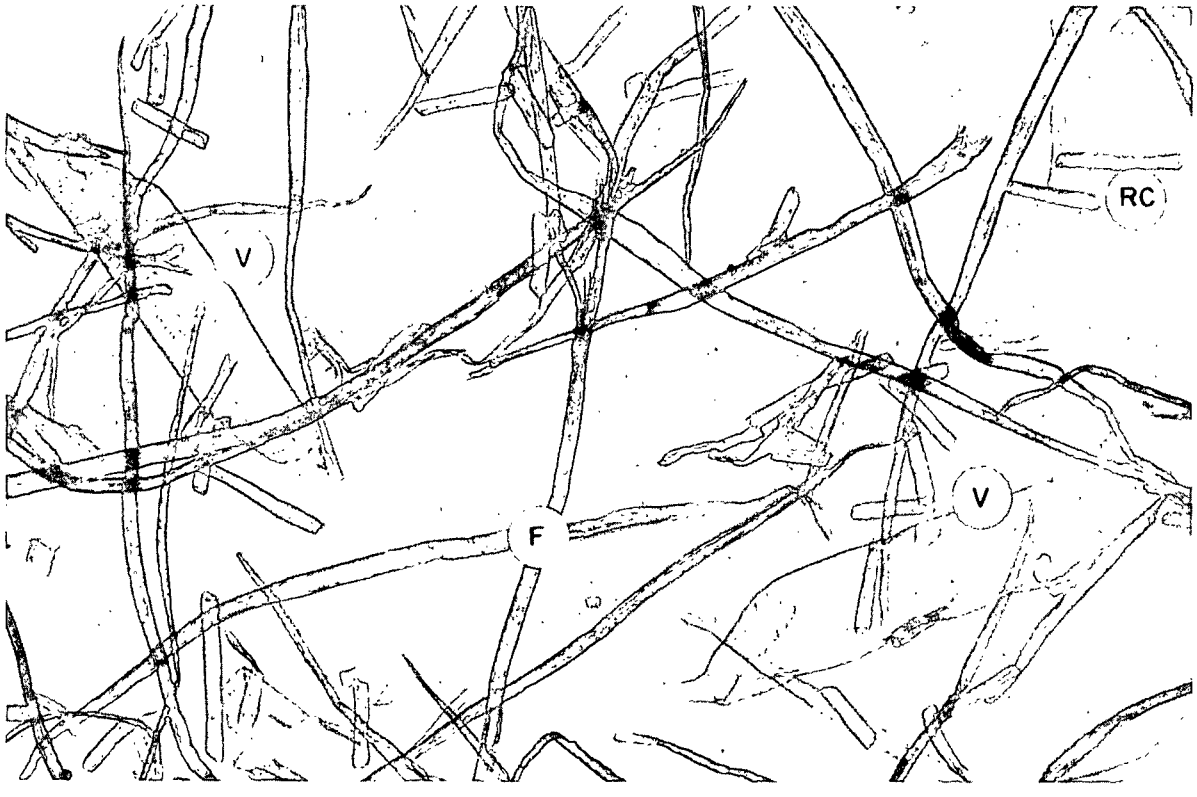


Figure 24. Pulp Sample of Yellow-Poplar Unbleached Kraft (IPC 3033-17). Vessel (V), Fibers (F), Ray Cells (RC). Magnification — 90 Diameters. Average Weight Factor of Yellow-Poplar Chemical Pulps — 0.72

HICKORY (Shagbark Hickory [Carya ovata (Mill.) K. Koch])

General Description and Minute Anatomy

Shagbark hickory is a ring porous wood, with large earlywood pores, visible to the naked eye. The transition from early to latewood is abrupt. The pores in the latewood are small, visible with a hand lens, solitary and in multiples of 2-3. Parenchyma are conspicuous with a hand lens in fine, continuous, tangential lines which are arranged irrespective of the pores. The rays are indistinct without a hand lens. The wood is heavy to very heavy (sp.gr. 0.56-0.66 green, 0.62-0.78 ovendry). There are 2-11 vessels per square millimeter, the largest springwood vessels are 160-320 μm. in diameter and average 0.47 mm. in length. The fibers are thin to thick-walled, frequently gelatinous, 12-20 μm. in diameter and 1.34 mm. in length. Rays are 1-5 seriate, homogeneous to heterogeneous.

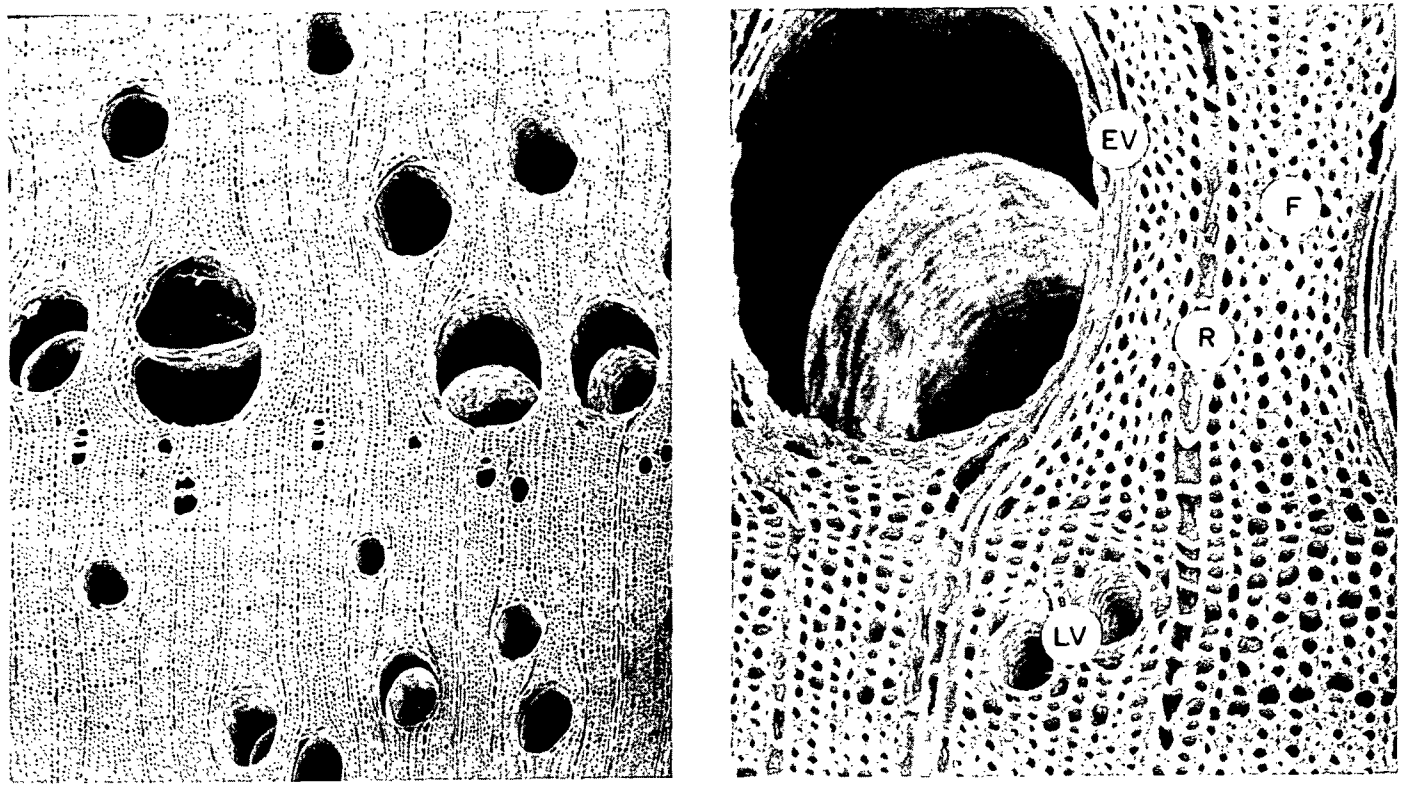
Photomicrographs (SEM) of transverse surface areas of shagbark hickory are illustrated in Fig. 25 and 26.

Weight Factor Determination

The results of a weight factor determination made on a pulp sample prepared from species of shagbark hickory are shown in Table XII.

Hickory presently is not widely pulped but is in reasonable supply. The fiber characteristics of other species of hickory are expected to be similar to those of shagbark hickory and a weight factor of 0.34 is recommended for chemical pulps of hickory.

A photomicrograph of the pulp furnish is illustrated in Fig. 27.



Figures 25 and 26. Shagbark Hickory [Carya ovata (Mill.) K. Koch] Photomicrographs (SEM) of Transverse Surface of Shagbark Hickory. Earlywood Vessel (EV), Latewood Vessel (LV), Fiber (F), Ray (R). 2-11 Vessels per sq.mm. Magnification 50-200 Diameters

TABLE XII

WEIGHT FACTOR DETERMINATIONS ON SHAGBARK HICKORY PULP SAMPLES

Pulp Sample	Weight Factor Determination		
	Analyst A	Analyst B	Av.
Shagbark hickory — unbleached kraft — IPC Sample 3033-2	0.35	0.34	0.34

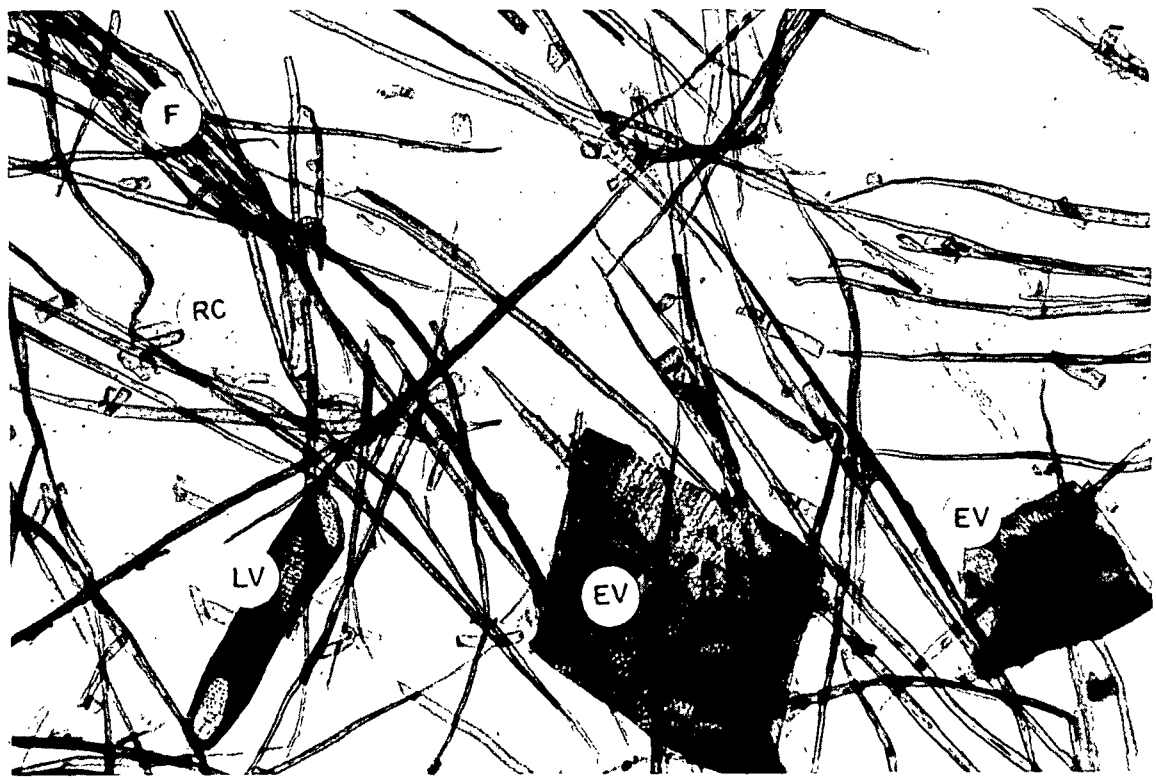


Figure 27. Pulp Sample of Shagbark Hickory Unbleached Kraft (IPC 3033-2). Earlywood Vessel Element (EV), Latewood Vessel Element (LV), Fibers (F), Ray Cells (RC). Magnification — 90 Diameters. Weight Factor of Pulp Sample — 0.34

DISCUSSION OF RESULTS

TAPPI Standard Method T 401 m-60 (see Table II, p. 9, Progress Report One) suggests the use of a weight factor of 0.60 for all chemical hardwood pulps except gum. For gum a weight factor of 1.0 was recommended. The results of this investigation confirm earlier findings by Landes (3) and Graff (4) that there are marked variations in the weight factors of pulps prepared from different wood species. The results of this research suggest that a number of different weight factors should be used for hardwood pulps rather than a single value of 0.60. This current study, limited to pulps prepared from species of hardwoods, show weight factor values ranging from an average value of 0.33 for maple chemical pulps to an average value of approximately 0.8 for chemical pulps prepared from species of sweetgum.

The range and mean of the weight factor values determined for the pulp samples of each species are illustrated in Fig. 28. The average standard deviation of the mean ($s_{\bar{x}}$) for Analyst A is 0.012 and Analyst B 0.018. Pulps prepared from species of maple, hickory, and white ash have low coarseness* and a weight factor <0.4. Populus sp., white and red oak chemical pulps have slightly higher coarseness and average weight factor values >0.4 and <0.5. Pulps prepared from beech and white birch had average factors >0.5 and <0.6, while the relatively coarse hardwood pulps prepared from yellow poplar, black tupelo, and sweetgum had average weight factor values >0.7 and <0.8.

It is recognized, as was stated in Progress Report Two, that variations occur in specific gravity, fiber length, width, etc., within trees and between trees of any species. The two samples of black tupelo examined in this

*Coarseness is defined as the weight per unit length of fiber, expressed as milligrams/100 m.

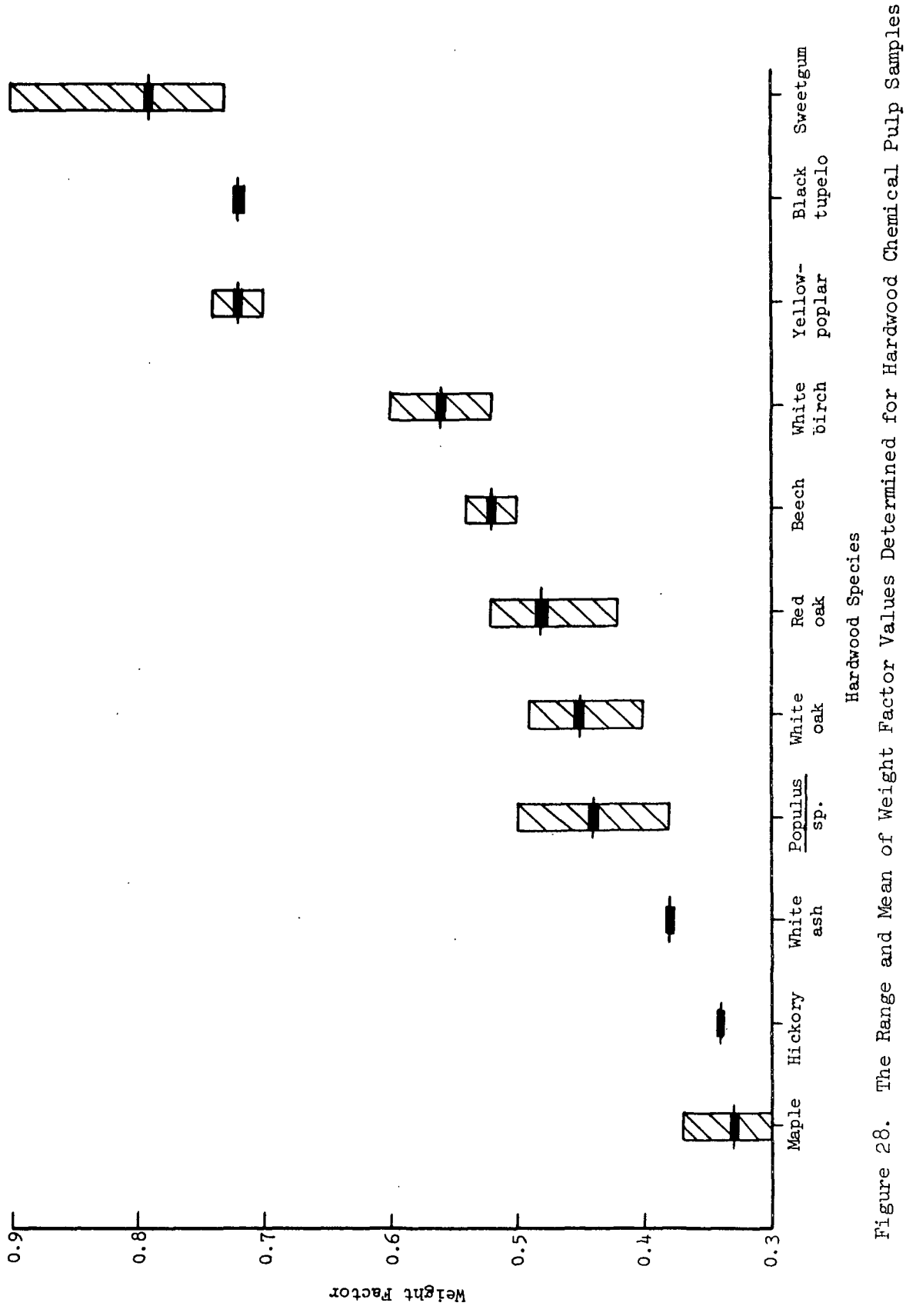


Figure 28. The Range and Mean of Weight Factor Values Determined for Hardwood Chemical Pulp Samples

present study, coded IPC unbleached kraft No. 3033-18 (Ala.) and IPC unbleached kraft No. 3033-22 (Va.) had specific gravity values of 0.514 and 0.476, respectively. Pulp sample No. 3033-22 was estimated to have almost double the number of vessel elements as the pulp prepared from Sample No. 3033-18. (see photomicrographs of transverse surfaces of wood samples, Fig. 29 and 30). The weight factors determined for the pulps prepared from these two samples, however, are approximately the same, 0.73 (Sample 3033-18) and 0.71 (Sample 3033-22).

The data obtained in this study would indicate that variations in wood density have little effect on the ultimate weight factor values that should be used for a particular wood species. There is a considerable variation in coarseness and weight factor values, however, between tree species and discretion should be used in the choice of weight factors employed in fiber analysis work. The suggested relative weight factor values for the various hardwood species should be beneficial in more accurate quantitative analysis determinations of pulp and paper furnishes.

RELATIVE FACTORS OF HARDWOOD PULPS BASED ON RATIO OF VESSEL ELEMENTS

INTRODUCTION

The pulping of hardwoods has increased greatly the past five years and even greater use of hardwoods is expected in the future. Cooking of species mixtures and the need to identify and evaluate hardwood mixtures is expected to be an increasing problem. The morphological characteristics of hardwood fibers (i.e., libriform fibers, fiber tracheids, and tracheids) are, in most instances, too similar to make a satisfactory species separation and quantitative analysis of a mixed hardwood pulp furnish. The vessel elements of hardwoods, however, are distinctive and easy to identify and their relative numbers in a pulp sample can be readily estimated. It is recognized that vessel numbers vary in the same wood species and many vessels, particularly large springwood vessels in ring porous woods may be lost or destroyed during pulp preparation. Nevertheless, a set of relative factors based on "vessel count" is a valuable tool in the estimation of the weighted percentages of hardwood species contained in a pulp mixture.

METHODS AND MATERIALS

Methods

The methods employed for the determination of a set of relative factors for hardwood pulps, based on the ratio of vessel elements, are very similar to those described for the determination of standard weight factors. A fifty-fifty mixture by weight of a specially prepared aspen standard pulp and the hardwood pulp being investigated are thoroughly mixed in a large Erlenmeyer flask. This fiber suspension is poured into six test tubes which are diluted to the desired

consistency (i.e., approximately 0.05-0.10%). Standard slide preparations are made from each suspension, the total one-square-inch areas (two per slide) are scanned under the microscope, and the vessels counted. All vessels and pieces of vessels estimated to represent one half or more of a vessel element are included in the counts. The aspen pulp, employed as a standard, has an assigned vessel count factor of 0.3.

SAMPLES

The samples used to determine the set of relative factors based on "vessel counts" were laboratory pulps prepared at The Institute of Paper Chemistry and described previously in the report (see Tables II and III). The aspen kraft pulp used as a standard was prepared from bolts which were debarked and chipped to a nominal 3/4-inch chip size. The cooking conditions, yield, etc., of the pulp are described in Table XIII.

TABLE XIII

COOKING CONDITIONS AND YIELD OF ASPEN PULP STANDARD

Digester charge, kg. o.d.	3.802
Liquor-to-wood ratio	4.5:1
Active alkali as NaOH, %	25
Sulfidity, %	25
Time to max. temp., min.	120
Time at max. temp., min.	60
Max. temp., °C.	172
Total yield, %	52.6
Screened yield, %	52.4
Kappa number	31.7

RESULTS AND DISCUSSION OF VESSEL COUNT FACTORS

The results of relative factor determinations based on vessel counts of hardwood pulps are listed in Table XIV. The overall agreement of results between analysts for all the pulp samples is very good. There is a considerable difference, however, between the factors determined for the two samples of black tupelo. The sample coded IPC 3033-18 (sp.gr. 0.514) had a factor of 1.23 or almost double the value determined for the pulp prepared from the sample of this wood species coded 3033-22 (sp.gr. 0.476). The difference in the number of vessels per unit area of wood between the two samples is illustrated in Fig. 29 and 30. It was anticipated at the outset of this investigation that the vessel numbers would vary between trees of the same species. This variation is undoubtedly greater between individual trees than between stands and stands from different geographical areas. Regardless of these recognized variables, average relative factors applied to vessel counts should give reasonably accurate estimates of the weighted percentages of hardwood species contained in a pulp mixture.

Results of this investigation indicated a broad range of vessel factors having a low of 0.2 for species of basswood and a high of 6.0 for species of red oak. The factors for ring porous species are much higher than the factors for most diffuse porous species, as would be expected. Pulps prepared from species of white oak have considerably lower values than red oak pulp samples.

Some work on vessel count factors was done prior to the initiation of Project 3033 using pulps with similar cooks, yield, etc., selected from the TAPPI Fibrary. These results (Study A) and the results of the current investigation (Study B) are listed in Table XV, together with suggested vessel factor values for each species.

TABLE XIV

VESSEL COUNT FACTORS

Pulp No.	Pulp Sample	No. of Vessels per sq.mm.[a]	Factor Determination[c] Analyst A Mean	Analyst B Mean	Av.
1	Aspen, standard pulp	85-180	0.3[b]	0.3	0.3
2	Yellow-poplar (IPC 3033-17)	60-180	0.83	0.82	0.82
3	Yellow-poplar (IPC 3033-23)	60-180	0.51	0.50	0.50
4	American beech (IPC 3033-26)	50-200	0.56	0.50	0.53
5	Southern cottonwood (IPC 3033-4)	30-145	0.57	0.56	0.56
6	Northern cottonwood (IPC 3033-25)	30-145	0.56	0.55	0.56
7	Sweetgum (IPC 3033-16)	120-180	0.56	0.61	0.58
8	Sweetgum (IPC 3033-21)	120-180	0.61	0.59	0.60
9	Black tupelo (IPC 3033-22)	90-180	0.63	0.61	0.62
10	Black tupelo (IPC 3033-18)	90-180	1.20	1.27	1.23
11	Soft maple (IPC 3033-3)	30-80	0.75	0.77	0.76
12	Soft maple (IPC 3033-7)	30-80	0.85	0.88	0.86
13	White birch (IPC 3033-1)	50-100	1.40	1.40	1.40
14	White oak (IPC 3033-19)	20-120	1.59	1.53	1.56
15	White oak (IPC 3033-24)	(in summerwood)	2.11	2.22	2.16
16	Bur oak (IPC 3033-13)		1.65	1.76	1.70
17	Post oak (IPC 3033-15)		2.30	2.40	2.35
18	White ash (IPC 3033-5)	6-15	3.10	3.10	3.10
19	Shagbark hickory (IPC 3033-2)	2-11	4.60	4.30	4.45
20	Red oak (IPC 3033-6)	10-30	4.90	5.01	4.96
21	Southern red oak (IPC 3033-14)	(in summerwood)	6.10	5.90	6.00
22	Southern red oak (IPC 3033-20)		6.70	7.70	7.20

[a] Cross-sectional area of wood.

[b] Assigned value for pulp standard.

[c] Standard deviation of the means were similar for Analysts A and B and were approximately 0.05 for species with vessel count factors <1.5. For species with vessel count factors of 1.5-4.0 the $s_{\bar{x}}$ was approximately 0.30. For species where the vessel count factors were from 4.5 to 7.2 the $s_{\bar{x}}$ was approximately 0.50.

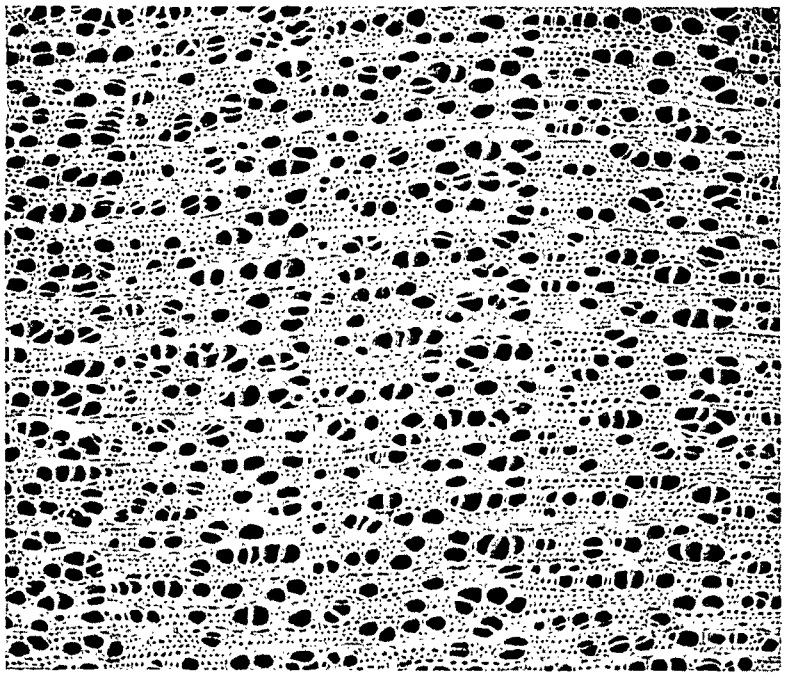


Figure 30. Black Tupelo (Nyssa sylvatica Marsh.) Photomicrograph (SEM) of the Transverse Surface of Wood Sample IPC No. 3033-22

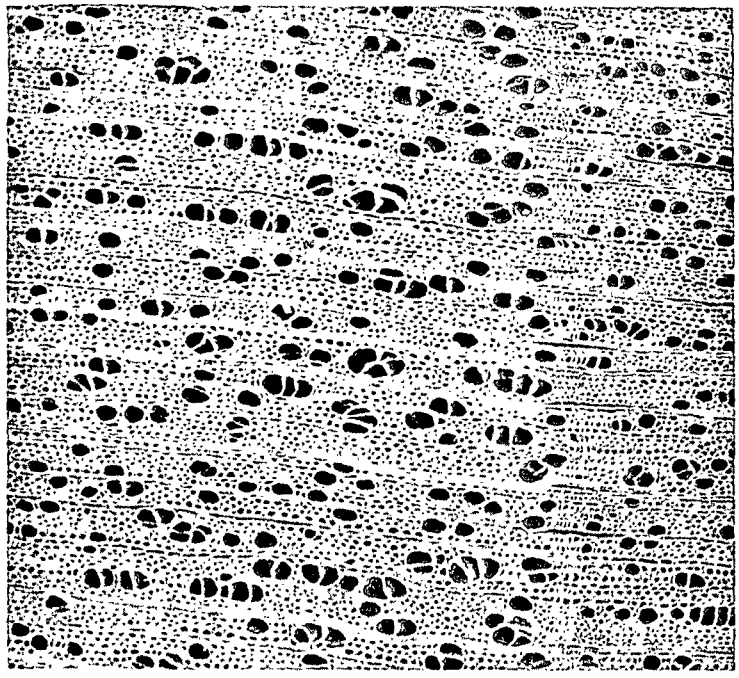


Figure 29. Black Tupelo (Nyssa sylvatica Marsh.) Photomicrograph (SEM) of the Transverse Surface of Wood Sample IPC No. 3033-18

TABLE XV

RELATIVE FACTORS OF HARDWOOD PULPS BASED ON RATIO OF VESSEL ELEMENTS

Species	Vessel Factor Determination		Suggested Factor
	Study A	Study B	
Basswood	0.2	--	0.2
Aspen	0.3	0.3	0.3
Populus sp.	--	0.55	0.5
Beech	--	0.53	0.5
Gum (species of blackgum and red-gum	0.5	0.6	0.6
Yellow-poplar	0.5	0.65	0.6
Maple	0.6	0.8	0.8
Birch	1.0	1.4	1.4
White oak	1.5-2.5	2.0	2.0
Ash	--	3.1	3.0
Hickory	--	4.5	4.5
Red oak	--	6.0	6.0

In conclusion, it is emphasized that these vessel factors have no relationship to coarseness and should not be confused with the conventional or standard weight factors of pulps. They are relative factors, based on the average ratio of vessel elements, which are applied to vessel counts in order to make a reasonable estimate of the weighted percentages of the different hardwood species contained in a pulp mixture.

An example of the results of a vessel count and analysis of a typical pulp containing a mixture of southern species of hardwoods is shown in Table XVI.

TABLE XVI

VESSEL COUNT AND ANALYSIS OF A TYPICAL PULP CONTAINING A MIXTURE OF SOUTHERN HARDWOODS SPECIES

Species	Vessel Count	Percentage by Count	Vessel Factor	Refined Count	Weighted Percentage	Reported Estimated Percentages
Red and white oak	26	15	3.0	78	45	40-50
Gum	68	40	0.6	41	23	20-30
Yellow-poplar	38	22	0.6	23	13	10-20
Maple	14	8	0.8	11	6	5-10
Birch	8	5	1.4	11	6	5-10
Beech	6	4	0.5	3	2	<5
Ash	2	1	3.0	6	3	<5
Basswood	6	4	0.2	1	1	<1
Populus sp.	2	1	0.5	1	1	<1

PLANS

Plans for the program during the next six months will be to complete weight factor determinations on pulp samples prepared from high priority species of softwoods.

ACKNOWLEDGMENTS

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GLOSSARY

Apotracheal parenchyma. Axial parenchyma typically independent of the pores or vessels. (Formerly known as metatracheal.)

Biseriate ray. Ray consisting of two rows of cells, as viewed in the tangential section.

Epidermis. The outer single layer of cells on an organ.

Epithelium. Excreting parenchymatous tissue surrounding the cavity of resin and gum canals.

Metatracheal parenchyma. Parenchyma in the body of the ring the cells of which are relatively abundant and are loosely grouped into lines or bands; in hardwoods, mostly independent of the vessels.

Paratracheal parenchyma. Parenchyma obviously associated with the vessels.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Ray. Ribbon-shaped strand of tissue extending in a radial direction.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin.

SEM. Scanning electron microscope.

Tracheid. Fibrous lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm.) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm.), are as long as the vessel elements with which they are associated, and possess small bordered pits.

Tyloses. Saclike or cystlike structures that sometimes develop in a vessel and rarely in a fiber through the proliferation of the protoplast (living contents) of a parenchyma cell through a pit pair.

Tylosoids. Balloonlike structures in resin canals resembling tyloses in hardwoods.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface or in a tangential section.

Uniseriate. Arranged in a single row, series, or layer. Also said of a wood ray which is one cell wide in cross section.

Vasicentric. Paratracheal.

Vessel. Composite, and hence articulated, tubelike structure found in porous wood (hardwoods), arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the common walls.